The influence of micrometeorological factors on the calling activity of the frog *Crinia signifera* (Anura: Myobatrachidae)

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ABSTRACT

I recorded the calling activity of the males of a population of the common eastern froglet *Crinia signifera* during 1988 to determine the seasonal and temporal patterns of calling activity and the influence of micrometeorological variables on calling. The patterns of calling were recorded using an automated cassette recorder switched on for 10 seconds approximately every 15 minutes. To assess the effects of micrometeorology on calling I compared the mean hourly calling activity with air temperature, barometric pressure, humidity, rainfall and wind intensity with time of day as a co-variable. This comparison was undertaken for data from three separate two-month periods of the year, as well as with the data from the three periods combined, to determine if there were seasonal differences in the effects of micrometeorology. For the analysis I used a forward stepwise Generalised Linear Model. Chorusing was recorded in every month of the year. Time of day was highly significant as a predictor of hourly calling activity in all of the tested periods, with calling being strongly associated with the hours of darkness. Rainfall over the preceding three days statistically explained a significant proportion of variation in hourly calling when the data from the three periods was combined, but only weakly so. Daily rainfall was the only (weakly) significant predictor within a period and only in January-February. The micrometeorological factor influencing calling activity in this study differs from those reported for other species. This may be because this population of *C. signifera* lives in a relatively benign, temperate environment where all seasons have at least moderate levels of rainfall.

Key Words: Micrometeorology, calling activity, common eastern froglet

Introduction

Studies on the environmental correlates of breeding in amphibians have indicated that reproductive activity can covary with a number of meteorological factors. Most commonly, changes in reproduction have been found to be linked to increases in temperature (e.g., Einem and Ober, 1956; Licht, 1969), rainfall (e.g., Balinsky, 1969; Telford and Dyson, 1990; Krupa, 1994) or a combination of both (Storm, 1960; Humphries, 1979; Okuno, 1985). However, reproductive activity may also be affected by other factors such as variation in light intensity (Savage, 1961; Rabb and Rabb, 1963), barometric pressure (Blankenhorn, 1972) or wind intensity (Robertson, 1986). Reliance on environmental cues to initiate breeding can result in significant variation in the reproductive period from year to year, with the times of onset of suitable conditions varying among years (Dankers, 1977; Mac Nally, 1983; Ritke et al., 1992).

The common eastern froglet, Crinia signifera, is a small myobatrachid frog from south-eastern Australia that is known to breed at both ephemerally and permanently flooded sites (Cogger, 1992; Barker et al., 1995). Studies of this species have provided contradictory results regarding the duration of its breeding activity. Earlier workers considered this species a year-round breeder (Fletcher, 1889; Harrison, 1922; Parker, 1940). However, more recent studies have suggested that C. signifera has an extended but specific breeding season from mid-winter to early summer, with no reproduction occurring from mid-summer to late-autumn. This was the case in studies by Dankers (1977) at Gosford, New South Wales (N.S.W), Humphries (1979) near Gundaroo, N.S.W., and by Mac Nally (1982) at Kilmore, Victoria. However, Dankers (1977) also noted that at Gosford, C. signifera reproduced at any time of the year in temporary aquatic environments, but in permanent aquatic situations this species exhibited a seasonal breeding period covering winter and spring. Straughan and Main (1966) indicated that temperature may control the calling activity of montane populations where calling was restricted to air temperatures of less than 18°C. This conclusion would support a winter/spring-based breeding season, with summer temperatures too high for calling.

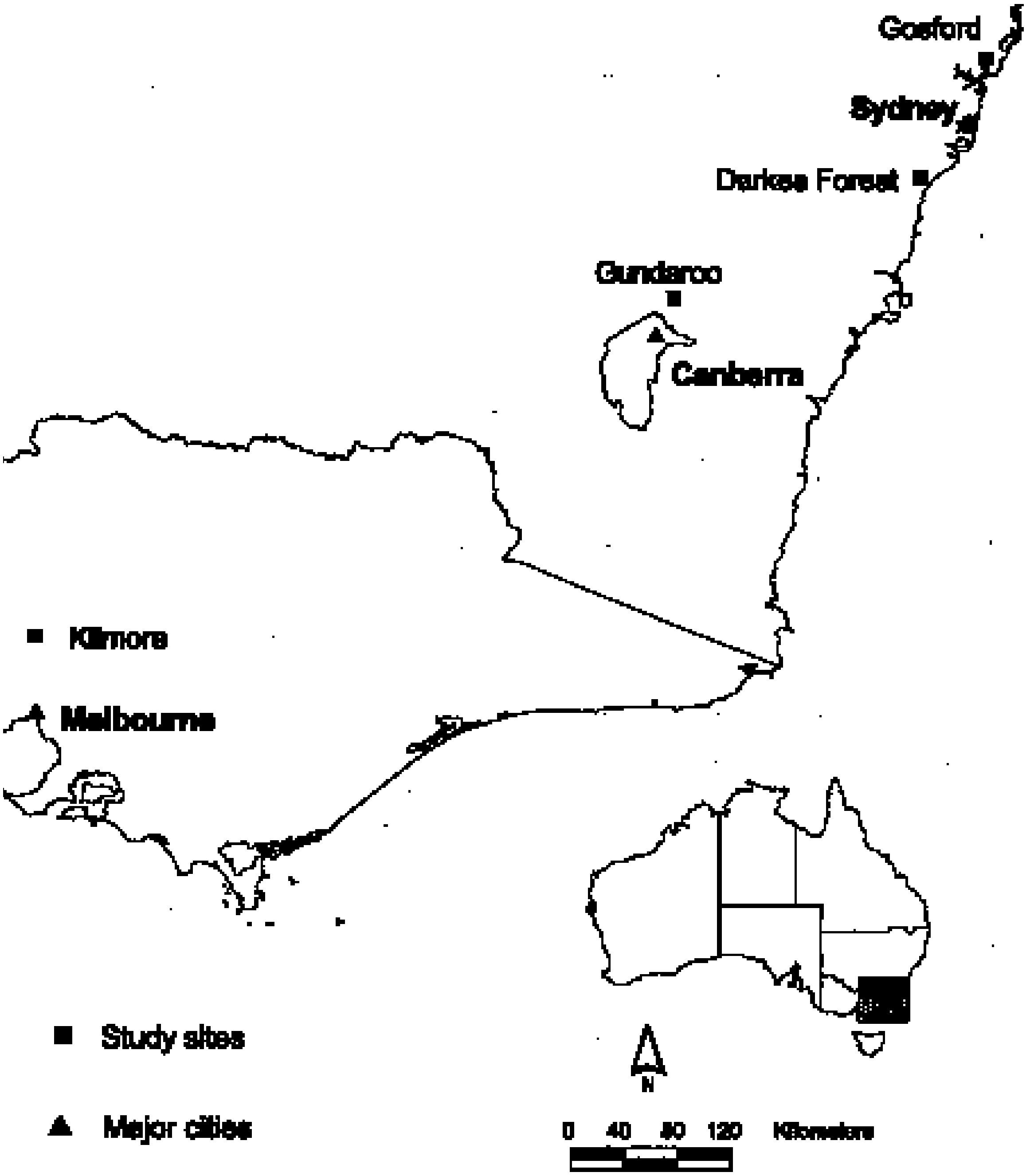

Figure 1. Location of the Darkes Forest Study Site and those of Dankers (1977), Humphries (1979) and Mac Nally (1982)

I studied a population of C. signifera at a low-elevation site in coastal N.S.W. to document the seasonal timing of calling and to examine the influence of meteorological factors on calling activity. I particularly wanted to determine if this population of frogs did call all year round and, if so, consider why this population acts differently from those looked at by other workers.

Materials and Methods

Study Site. The study was performed at a 30 m long X 18 m wide permanent pond located at Darkes Forest, approximately 50 km south-west of Sydney, N.S.W. (Figure 1). The body of the pond had a mean depth of approximately 50 cm and a maximum depth of 1.5 m. The bottom of the pond was 70-80% mud and silt and the rest covered by reeds (Typha sp.) and unidentified plants. The bank of the pond was four to six metres in width with a covering of either bare soil and rock, or grass and low shrubs (50/50). Cover in the next 20 m beyond the bank consisted variously of grass (50%), unsealed road (25%) and regenerating native vegetation (25%). Beyond this point, fruit orchards were present in a belt to the north and north-east with native heath and woodland being present elsewhere.

Meteorological Variables. Air temperature (± 0.1^0 Celsius), humidity (± 1%) and barometric pressure (± 1 Kilopascal) were recorded at the study site using a Lambrecht Thermohydrograph. This instrument was housed in a louvered “weather box” that was placed on the bank of the study pond, three metres from the waters edge. I assumed that, being so close to the breeding area of the frogs, the thermohydrograph would reasonably reflect the micro-meteorology conditions encountered by the breeding frogs. Rainfall records were obtained from the N.S.W. Bureau of Meteorology and had been recorded on a property one kilometre west of the study site. Wind intensity was estimated from the tape recordings of calling activity (see below) through the sound of the wind passing over the microphone and its protective housing. To provide a gradation in wind intensity, each ten second period was given a value ranging from 0 (no wind) to 3 (continuous strong winds) which was averaged over each hour.

Calling Activity. Advertisement calling of male frogs was monitored during each month of 1988 using a method modified from that of Dankers (1977). A Hodgeson portable cassette recorder and Sony standard condenser microphone was housed two metres from the edge of the study pond with the microphone directed towards the pond at a height of approximately 80 cm. Every 15 minutes an electronic timer switched on the cassette recorder for 10 seconds in order to record the calling activity at regular intervals throughout the day.

For analysis, the calling intensity over each 10 second period was scored on a scale of 0 to 3 with 0 = no calling, 1 = scattered calling by one to four males, 2 = scattered calling by five or more males, and 3 = continuous calling by five or more males. When I was uncertain as to which value to assign, the lower value was used. The scores from each hourly period were averaged to give hourly mean calling for use in the analyses.

Analyses. To assess the effects of micro-meteorology on calling I compared the mean calling activity recorded hourly with the air temperature, humidity and barometric pressure recorded on the Thermohydrgraph at the start of that hour. The mean hourly calling rate was also compared to the rainfall recorded for that day and with the combined rainfall recorded for that day and the previous two days (three-day rainfall). I recognised that there would be strong autocorrelations between the data from consecutive hours that might confound the analyses. To avoid this problem as far as possible, I used a random numbers table to select between one and eight of the one-hour periods from each day and used this subset of data in the analysis. The data used in this analysis was obtained from three separate two-month periods of the year that represented different climatic conditions and seasons. These were January-February that are warm and wet summer months, April-May that are cooler autumn months and August-September covering cold late winter and early spring. The data from these three periods were analysed separately to determine if the effects of micrometeorology varied between seasons as well as being combined to see if there is a broader overall pattern.

A visual assessment of the data indicated that rainfall and wind level were both non-normal in distribution and could not be normalised. Hence, I carried out a forward step-wise analysis of covariance using a Generalized Linear Model (GLM) to assess the relationships of mean hourly calling with the micrometeorological variables. I also recognised that there was likely to be a very strong and simple relationship between calling activity and the hours of darkness and temperature and humidity and whether it was day or night. To account for this factor, time of day was used as a categorical co-variable. Each four hour period starting from 1:00 AM was considered a separate category thus breaking the 24 hour period into six categories that were generally either night or day blocks of time.

The significance of the explanatory variables was tested with the Wald statistic, which is calculated by the maximum likelihood ratio. A poisson distribution and log-link function was used for the stepwise procedure and the P to enter and remove both set at 0.05. The goodness of fit of the observed data was compared with the predicted values and normal probability plots to assess the adequacy of the model. All tests were carried out using Statistica Version 5.5 (Statsoft, USA).

Results

Calling Activity. Strong calling was recorded for this frog in every month of the year (see Figure 2). Peak calling activity occurred from July to November (winter-spring) and the least calling activity was in April/May (autumn). Nights without any identifiable chorusing activity were rare (<20). The longest sequence of nights without chorusing was three nights, but even then males still called sporadically.

Calling commenced or increased markedly at sunset, usually resulting in a change from no calling to intense chorusing within a 15-minute period, and then often remained at relatively increased levels throughout the night before decreasing rapidly at sunrise (Figure 2). Calling activity during the daylight hours from January to March was almost always restricted to sporadic calling by a few individuals. In the cooler months however (particularly July to September), larger numbers of males were regularly recorded calling and even occasionally chorusing during the day (Figure 2). There were occasional periods of intense daytime calling and during mid-October 1987, chorusing occurred almost continuously for 60 hours.

The co-variable time of day was found to be an extremely strong predictor of hourly calling activity when all the data was combined (n = 581; Wald Statistic = 184.68; Wald $P < 0.00001$). That is, more intense calling was very strongly correlated with the hours of darkness. Of the measured micrometeorological variables a positive association with three-day rainfall explained a significant proportion of variation in calling

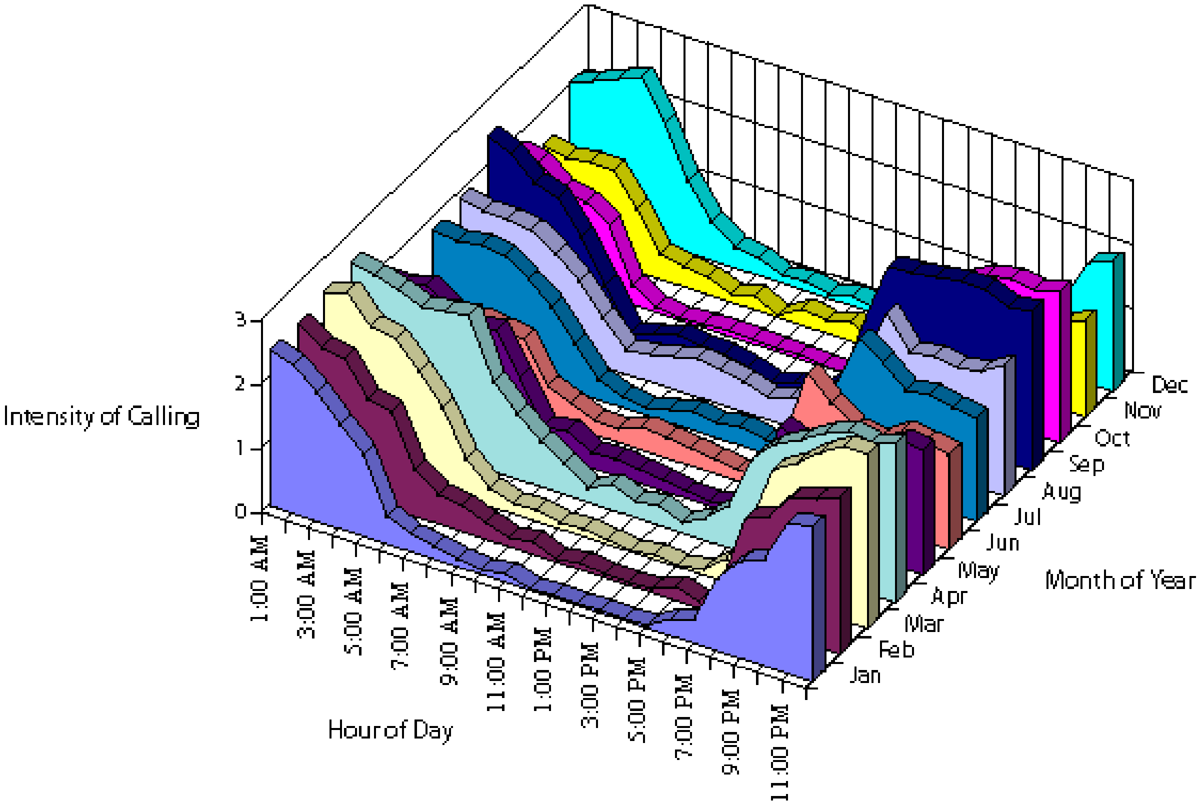

Figure 2. Mean hourly calling activity of male frogs during each month of 1988 (ranging from no calling = 0 to continuous chorusing = 3 recorded over 10 seconds every 15 minutes).

activity (n = 581; Wald Statistic = 11.40; Wald P < 0.001). A check of the observed data against the predicted modelled values however, indicated some scatter in the plot, suggesting that three day rainfall was not a strong predictor of calling activity.

The co-variable time of day was again a very strong predictor of hourly calling activity in each of the January-February (n = 175; Wald Statistic = 71.68; Wald P < 0.00001), April-May (n = 196; Wald Statistic = 66.66; Wald P < 0.00001) and August-September (n = 210; Wald Statistic = 25.48; Wald P < 0.00005) periods. Only one significant micrometeorological predictor was recorded and only for one period. This was daily rainfall for the January-February (summer) period (n = 175; Wald Statistic = 8.58; Wald P < 0.005). Again however, the predicted model did not fit well with the observed data and so daily rainfall should only be considered a partial predictor of calling activity.

Temperatures above 18° C were not seen to suppress calling activity. Chorusing was recorded on 27 nights when air temperatures exceeded this value for the entire night and chorusing was recorded when the air temperature was as high as 26° C.

Discussion

In this study, C. signifera actively called during all months of the year and oviposition was also recorded in the pond in every month of the year (Lemckert, 1991). This result differs from those of Dankers (1977), Humphries (1979) and Mac Nally (1982) where this species was found to call and breed only from late autumn to early summer. This difference may be due to the fact that my study coincided with two years of above-average rainfall with levels during most of the months regularly exceeding the mean rainfall levels recorded historically for those months (see Figure 3). Mac Nally (1981) suggested that C. signifera may extend its breeding season in years when rainfall levels are unusually high. However, Darkes Forest was selected for the study because C. signifera was calling there throughout the drought year of 1986 and in 1987 and 1989 when other work was performed at this site (Lemckert, 1991). Both Dankers (1977) and Humphries (1979) also studied this frog at permanent pond sites and so the results are unlikely to be due to the presence of permanent water at my study site. Therefore, I hypothesise that C. signifera normally calls throughout the year at permanent ponds in the Darkes Forest area.

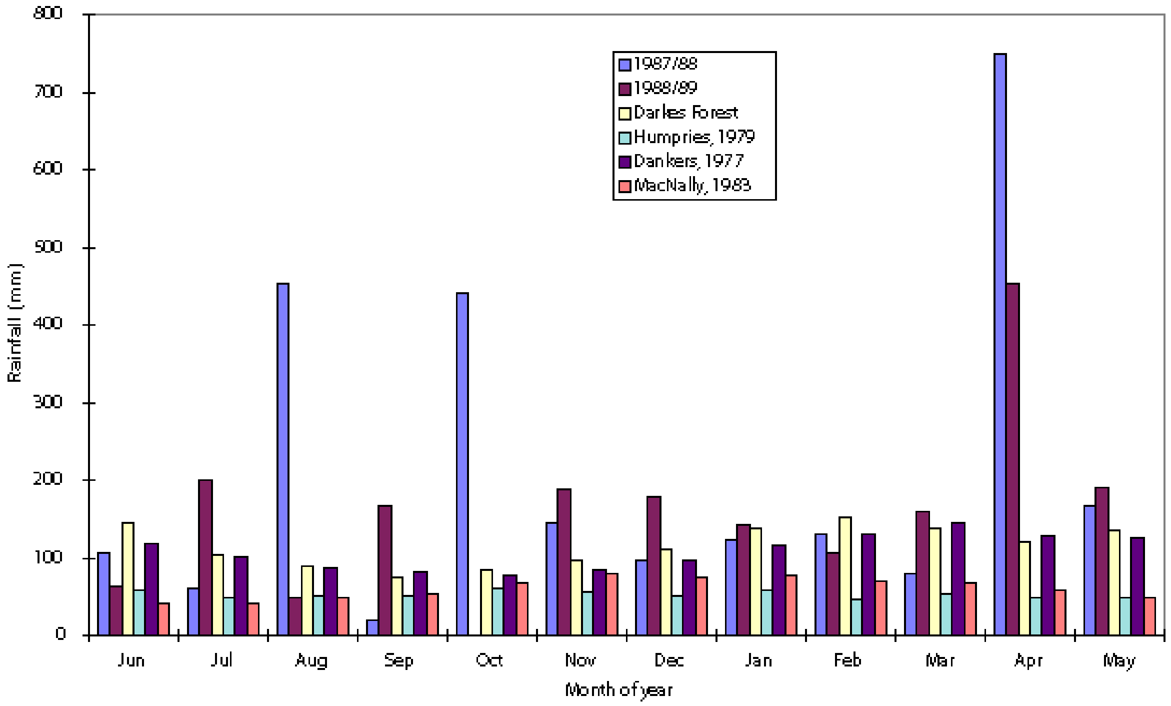

Figure 3. Mean long-term monthly rainfall at Darkes Forest compared to long-term mean monthly rainfall at the study sites of Dankers (1977), Humphries (1979) and Mac Nally (1983).

Darkes Forest has greater mean annual rainfall compared to the sites examined by Humphries (1979) and Mac Nally (1981 and see Figure 3), which may allow calling to occur at all times of the year irrespective of other environmental conditions. However, the period from December to March was the time of relatively greater rainfall in each of the study areas (Figure 3), yet was the time when frogs in the other studies were seasonally inactive. Furthermore, the rainfall patterns found in the area of Dankers' (1977) study are very similar to that of the Darkes Forest area, yet his frogs were also inactive when the frogs in my study were calling and breeding. Therefore, higher rainfall in the Darkes Forest area cannot explain the extended breeding season observed in my study.

The period of most calling activity at Darkes Forest (July to November = mid-winter to late-spring) corresponds to the entire calling season of C. signifera in the three other areas in which detailed studies were made (Dankers, 1977; Humphries, 1979; Mac Nally, 1983). This finding leads to the suggestion that there is some advantage to breeding during this period. Development of the tadpoles takes one to two months from egg to metamorphosis (Moore, 1961; pers. obs.). Therefore, tadpoles from winter-spring breeding would reach metamorphosis during spring and early summer. This period of emergence is probably an advantageous time for young frogs, because the warmest and wettest months are ahead and food availability should be highest at these times.

Other similar studies of temperate-zone anurans have most often recorded temperature to act as a significant cue for the onset and cessation of reproductive activity. However, these results have been obtained with species that have well-defined breeding seasons (e.g., Jackson, 1952; Blair, 1958; Dankers, 1977; Moreira and Barreto, 1997). In such cases, at least some part of the year does not represent a suitable time to breed. Darkes Forest had a mean winter minimum temperature during this study of 7° C and so temperatures may rarely ever fall to levels at which a frog is unable to be physically active. The relatively uniform climatic regime of Darkes Forest may very well have allowed C. signifera to evolve so that the calling activity of males has become reasonably, but not completely, independent of micrometeorological factors.

Dankers (1977) and Humphries (1979) specifically noted that daily rainfall had no significant influence on calling activity in their populations of C. signifera. I found rainfall to be important in determining the level of calling activity, but at an overall level, this was when rainfall levels were higher over the previous three days and not on the actual day of calling. Persistent rainfall results in saturation of the substrate and so may allow male frogs to call for sustained periods without suffering dehydration. It has been demonstrated in many species that male frogs that invest more energy in calling have greater reproductive success (reviewed by Halliday, 1987). Males at Darkes Forest may be able increase their calling activity at times of sustained rainfall and have to do so in order to compete against other calling males for the available females. The finding of rainfall on the day of calling being a significant factor in the January-February period adds some weight to the argument that desiccation may be important in determining male calling. This is the hottest period of the year and so the time when soil moisture will probably be retained for only relatively short periods of time leading to numerous days when calling is retarded by reduced soil moisture levels. Such problems would rarely arise in cooler months of the year.

The results of this study, when compared to other published studies on this species, indicate that there is geographic variation in the onset and length of the calling season, but the reasons for this variation remain uncertain. More work is required before we understand the reproductive habits of this geographically widespread species.

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References

Balinsky, B. I., 1969. The reproductive ecology of amphibians of the Transvaal high velt. Zoological Africana **4:** 37-93.

Barker, J., Grigg, G. C. and Tyler, M. J., 1995. A Field Guide to Australian Frogs. Surrey Beattey and Sons: Sydney.

Blair, W. F., 1958. Mating call and stage of speciation of anuran amphibians. American Naturalist **92:** 27-51.

Blankenhorn, H. J., 1972. Meteorological variables affecting onset and duration of calling in Hyla arborea (L.) and Bufo. b. calamita (Laur.). Oecologia **9:** 223-235.

Dankers, N. M. J. A., 1977. The ecology of an anuran community. Unpubl. PhD, University of Sydney: Sydney.

Einem, G. E. and Ober, L. D., 1956. The seasonal behaviour of certain Floridian Salientia. Herpetologica **12:** 205-212.

Fletcher, J. J., 1889. Observations on the oviposition and habits of certain Australian batrachians. Proceedings of the Linnaen Society of New South Waleas **4:** 357-387.

Halliday, T. R., 1987. Physiological constraints on sexual selection. Pp. 247-264 in Sexual Selection: Testing the Alternatives ed. by J. W. L. Bradbury and M. B. Andersson. John Wiley and Sons: Chichester.

Harrison, L., 1922. On the breeding habits of some Australian frogs. Australian Zoologist **3:** 17-34.

Humphries, R. B. 1979. Dynamics of a breeding frog community. Unpubl. PhD, Australian National University: Canberra.

Jackson, J. W., 1952. The effect of temperature, humidity, and barometric pressure on the rate of call in Acris crepitans Baird in Brazos County, Texas. Herpetologica **8:** 18-20.

Krupa, J. J., 1994. Breeding biology of the great plains toad in Oklahoma. Journal of Herpetology **28:** 217-224.

Lemckert, F. L., 1991. Aspects of the reproductive biology and population dynamics of the common eastern froglet, Ranidella signifera. Unpublished. MSc, University of Sydney: Sydney.

Licht, L. E., 1969. Comparative breeding biology of the red-legged frog (Rana aurora aurora) and the western spotted frog (Rana pretiosa pretiosa) in southwestern British Columbia. Canadian Journal of Zoology **47:** 505-509.

Mac Nally, R. C., 1981. On the reproductive energetics of chorusing males: Energy depletion profiles, restoration and growth in two sympatric species of Ranidella (Anura). Oecologia **51:** 181-188.

Mac Nally, R. C., 1982. Ecological, behavioural, and energy dynamics of two sympatric species of Ranidella (Anura). Unpubl. PhD, University of Melbourne: Melbourne.

Mac Nally, R. C., 1983. Trophic relationships of two sympatric species of Ranidella (Anura). Herpetologica **39:** 130-140.

Moreira, G. and Barreto, L., 1997. Seasonal variation in nocturnal calling activity of a savannah anuran community in central Brazil. Amphibia-Reptilia **18:** 49-57.

Moore, J. A., 1961. Frogs of eastern New South Wales. Bulletin of the American Museum of Natural History **121:** 153-385.

Okuno, R., 1985. Studies on the natural history of the Japanese toad, Bufo japonicus japonicus. VIII. Climatic factors influencing the breeding activity. Japanese Journal of Ecology **35:** 527-535.

Parker, H. W., 1940. The Australasian frogs of the family Leptodactylidae. Novitations in Zoology **42:** 1-106.

Rabb, G. B. and Rabb. M. S., 1963. On the behaviour and breeding biology of the African pipid frog Hymenochirus boettgeri. Zeitscrift fuer Tierpsychologie **20:** 215-241.

Ritke, M. E., Babb, J. G. and Ritke, M. K., 1992. Temporal patterns of reproductive activity in the gray treefrog (Hyla chrysoscelis). Journal of Herpetology **26:** 107-111.

Robertson, J. G. M., 1986. Female choice, male strategies and the role of vocalisation in the Australian frog Uperoleia rugosa. Animal Behaviour **34:** 773-784.

Savage, R. M. 1961. The ecology and life history of the common frog (Rana temporaria temporaria). Pitman: London.

Storm, R. M. 1960. Notes on the breeding biology of the red-legged frog (Rana aurora aurora). Herpetologica **16:** 251-259.

Straughan, I. R. and Main, A. R., 1966. Speciation and polymorphism in the genus Crinia Tschudi (Anura: Leptodactylidae) in Queensland. Proceedings of the Royal Society of Queensland **78:** 11-28.

Telford, S. R. and Dyson, M. L., 1990. The effect of rainfall on interclutch interval in painted reed frogs (Hyperolius marmoratus). Copeia **1990:** 644-648.